LCA Methodology

A Life Cycle Decision Methodology for Recycle of Radioactive Scrap Metal *

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Abstract

During the past five years, a number of U.S. Department of Energy (DOE) funded efforts have demonstrated the technical efficacy of converting various forms of radioactive scrap metal (RSM) into useable products. While health and safety and other technical issues have been addressed, the question remains: do the benefits of fabricating products from RSM outweigh the costs? This paper presents a decision methodology for use within DOE to evaluate the costs and benefits of recycling and reusing some RSM, rather than disposing of this RSM in an approved burial site. The methodology consists of two distinct phases: the Life Cycle Assessment phase and the decision phase. The Life Cycle Assessment approach proposed here differs from traditional life cycle assessments because it considers economic and other impacts of concern to stakeholders, and includes secondary and indirect impacts that may occur upstream or downstream of the decision.

Keywords: Decision analysis; industrial ecology; Life Cycle Assessment; metals recycle; methodology, LCA; radioactive scrap metal; RSM

1 Introduction

A goal of the emerging field of industrial ecology is to plug "leaks" in materials cycles, so that materials are not permanently disposed of and thus unavailable for future reuse. This is viewed by many as essential for achieving sustainable development [1,2,3]. However while the closing of materials cycles is often considered the environmentally preferred thing to do, such claims are often not accompanied by a rigorous evaluation of the costs and benefits of the recycle activities. Often the full life cycle economic, environmental, and other impacts of materials recycle are not assessed. A Life Cycle Assessment approach to evaluating the closure of materials cycles will examine the full economic, environmental, and other impacts of linear vs. cyclical materials flows and will ensure adequate consideration of costs and benefits in decision-making [4].

During the past five years, a number of U.S. Department of Energy (DOE) funded efforts have demonstrated the technical efficacy of recycling various forms of radioactive scrap metal (RSM) into useable products. While health and safety and technical issues have been addressed, the question remains: do the benefits of fabrication of products from RSM outweigh the costs? To answer this question, a Life Cycle Assessment approach was developed to provide a full perspective on the life cycle costs and benefits of RSM recycle.

This paper summarizes a methodology that was developed to help decision-makers to compare and select among competing proposals for the disposition of RSM at the DOE Fernald Environmental Management Project (FEMP) [5]. As part of the DOE's asset management initiative, a recycle alternative has been proposed for the FEMP cleanup program in which contaminated metals present at the site would be melted and fabricated into containers that would be used for transport and disposal of low-level radioactive waste (LLW). Currently, LLW is placed in purchased boxes made from virgin or recycled steel, which represent a "leak" in the steel cycle. Manufacturing boxes from RSM would plug the "leak" in this cycle [2,6].

The methodology developed takes into consideration both quantitative and qualitative factors in three general categories: direct financial costs and benefits; socio-economic and institutional impacts including regional economic impacts; and environmental, safety and health impacts (including ex-

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ternalities where possible). The methodology includes both the analytical requirements to develop defensible values for a comprehensive set of performance measures, and the structure for using the performance measures to compare and rank alternative proposals.

An important component of the decision methodology is the proposed Life Cycle Assessment approach for environmental decision-making. The Life Cycle Assessment approach proposed here differs from traditional life cycle assessments in its breadth, in that it encompasses all of the possible impacts of concern to decision-makers and stakeholders. For example, the Society of Environmental Toxicology and Chemistry (SETAC) defines "life-cycle assessment" as "an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements" [4,7]. The approach presented here differs from the SETAC approach because it considers the economic and other impacts of concern to stakeholders, and addresses secondary and indirect impacts that may occur upstream or downstream of the decision.

This methodology has been presented at a public meeting in Fernald, Ohio, to solicit public input, and at a DOE pollution prevention conference, and is scheduled to be applied across the FEMP complex.

2 Decision Methodology

A decision on RSM disposition alternatives should be based on two categories of information:

1. the potential impacts of choosing each of the candidate alternatives,
2. the value judgments used in evaluating these impacts.

Correspondingly, the methodology is divided into two phases: the Life Cycle Assessment phase, in which the possible impacts of each of the candidate alternatives are assessed; and the decision phase. In the first phase, the objectives and program scope are defined, the RSM disposition alternatives are identified, performance measures are specified, and the impacts of the alternatives are described in terms of the performance measures. In the second phase, the decision phase, the methodology will aid the decision-maker(s) in the comparison of alternatives and the selection of the preferred alternative.

2.1 Life Cycle Assessment Phase

Life Cycle Assessment is the process of identifying and assessing all benefits and costs that result from a course of action over the entire period of time affected by the action and providing the results in a form that will promote sound decision-making. A Life Cycle Assessment provides a logical approach to the comprehensive assessment of alternatives which is mandated by the uncertain, hidden, and at times counterintuitive costs and benefits of alternative proposals. The elements of a Life Cycle Assessment depend on the purpose of the analysis and the availability of specific data. In general, however, elements of a Life Cycle Assessment consist of direct costs and benefits, which derive from the outlays that DOE would expend; socio-economic and institutional impacts; and environmental, safety, and health impacts.

The proposed Life Cycle Assessment framework is illustrated in **Figure 1**. The first stage of the Life Cycle Assessment approach is the definition of decision parameters. This stage consists of three steps: define nature of decision and program scope, specify objectives and performance measures, and identify alternatives. The second stage of the Life Cycle Assessment phase is the evaluation of the impacts of the alternatives. In this stage, the analytical approach is defined for each of the performance measures, their value is estimated for each alternative, and the results are summarized for use by the decision-maker(s). These six steps that make up the Life Cycle Assessment are inter-linked and are described below. Although the entire methodology is an iterative process at every step, a feedback mechanism is indicated at the end of the second stage to emphasize that performance measures may be further refined, the system definition and process flow model revised, new strategic alternatives identified, and additional analyses performed.

2.1.1 Define nature of decision and program scope

A clear statement is needed of the current system and the nature of the decision that is required. This defines the study and the system boundaries from which viable alternatives can be defined and their impacts evaluated. It also defines the scope for which impact analysis is required. Finally, it helps in identification of possible decision-aiding approaches for use in the decision phase. This step also includes a preliminary assessment of the quality of the information available to perform the analysis, identification of the criteria for the quality and efficacy of the analysis, and a preliminary identification and inventory of assets and resources.
In defining the problem scope, the general rule for deciding whether or not a consideration should be included in evaluating metal disposition alternatives is whether or not that inclusion could have a significant impact on the evaluation of alternatives. As an example, if all alternatives being considered fully comply with all laws and regulations, then regulatory compliance could be eliminated from the comparative analysis of metal disposition alternatives. However, regulatory compliance would be relevant in deciding whether or not to include an alternative in the analysis. Similarly, if the aesthetic impacts were considered to be equivalent for all alternatives, this could be omitted in a comparative analysis. This general rule allows us to eliminate many considerations from the study.

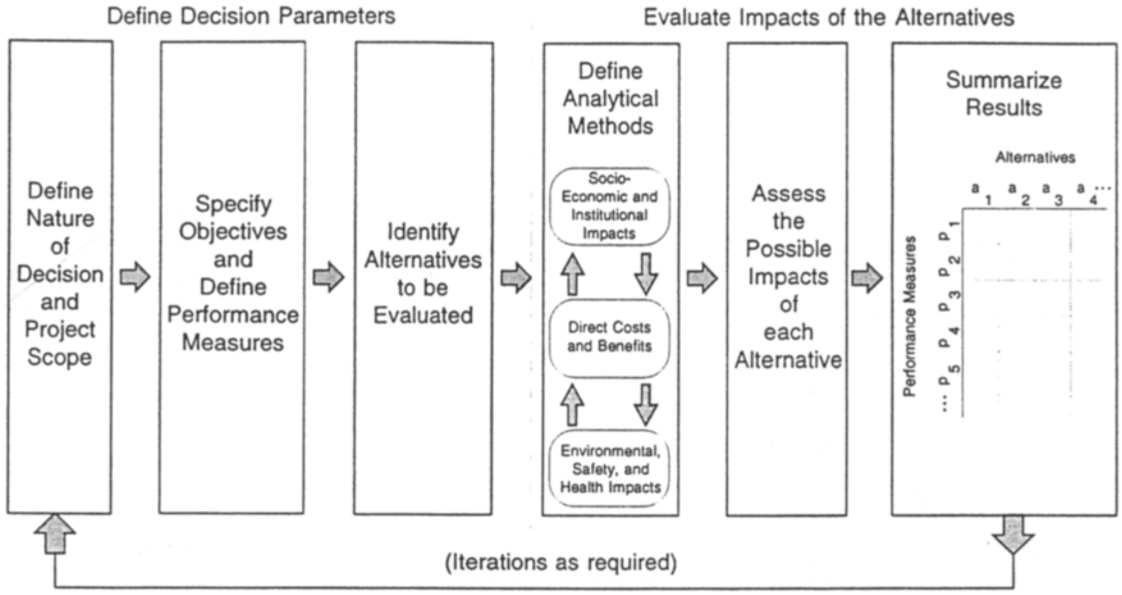

Fig. 1: Life Cycle Assessment Framework

2.1.2 Specify objectives and performance measures

To conduct an effective analysis, it is necessary that a clear statement be made of the program objectives, so that the intents and reasoning behind the program are well understood by the analysts, the decision-makers, and other stakeholders. In order to estimate how well proposed alternatives achieve the identified objectives, measures are needed to quantify that performance. Thus, the identified objectives are translated into attributes and corresponding measurement scales (performance measures) that relate descriptions of impact levels to quantitative or qualitative scores. This is an important step, because the performance measures determine the specific analytical approaches that will be taken in subsequent steps of the methodology and constitute the input to the decision phase.

The objectives, attributes, and their corresponding performance measures have been divided into three general categories, as depicted in **Figure 2**. The first category is the direct financial costs and benefits. This includes the more common analyses performed for decision-making, taking into account only those costs and benefits that are directly paid or received by the decision-making party (in this case, the DOE). The second category is socio-economic and institutional impacts. This relates to the economic, cultural, institutional, and social issues involved in most major public decisions. The third category, environmental, safety, and health impacts, addresses impacts to the environment and human health. Some issues, such as regulations, will have impacts in more than one area.

The set of performance measures should be decided upon in consultation with all stakeholders. The most important criterion for the set of performance measures is that collectively, the set of performance measures should capture all of the things that the stakeholders care about. Ideally, the performance measures should be mutually exclusive as well as collectively exhaustive. A working set of performance measures and the means for their analysis is presented below. It is entirely appropriate for the set of performance

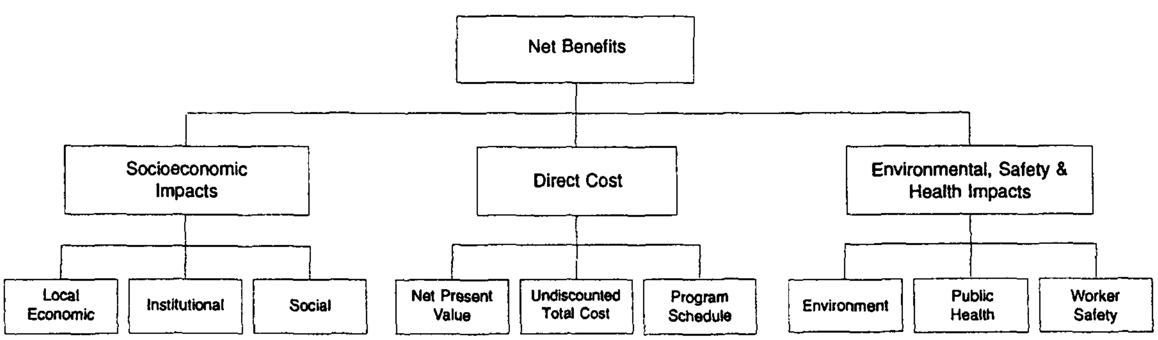

Fig. 2: General attributes identified for evaluating alternatives

measures to be refined as further information is developed and as the analysis proceeds. Several possible performance measures have been eliminated because they were considered not to differentiate among the alternatives under consideration.

- **Direct Costs and Benefits.** All major government decisions require a cost analysis. Depending on the scope of the analysis, the performance measures can be a summation of all costs, or the time value of money can be included through discounting. Guidance from the U.S. Office of Management and Budget requires the use of discounting. Many other factors intertwine with the financial cost: schedule changes can drive costs up or down, regulatory requirements may add costs to an alternative, and market prices for products may influence the net cost of an alternative. Three of the more common performance measures are net present value, total undiscounted cost, and schedule impacts.

  Net Present Value. The standard criterion for deciding whether a government program can be justified on economic principles is net present value – the discounted monetized value of expected net benefits (i.e., benefits minus costs). Net present value is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate social discount rate (or range of rates), and subtracting the sum total of discounted costs from the sum total of discounted benefits. Discounting benefits and costs transforms gains and losses occurring in different time periods to a common unit of measurement.

  Total Undiscounted Cost. Undiscounted total cost can be studied through the use of a zero discount rate in the analytical spreadsheet. This can be important for people concerned with issues such as inter-generational equity or the potential for large costs after the project is completed. By not discounting these future costs, the later high costs are highlighted.

  Schedule Impacts. The impact on program schedule as a performance measure will capture schedule delays or accelerations under the alternatives. The costs associated with schedule impacts are included in the two performance measures above, but schedule impacts in and of themselves are often important to decision-makers.

- **Socio-economic and Institutional Impacts.** While most economic factors are already captured in the direct cost analysis, some economic factors lie outside that analysis. Some of those include local economic impacts on the surrounding community, employment effects, property values, and the impact of the recycled material in the larger market for scrap metal or contaminated scrap metal. A simple method to analyze the impacts of economic inflows into a community is through an economic "multiplier". A more complex method used to study local economic impacts is an Input/Output model, such as the Oak Ridge Social Accounts Matrix (SAM). It characterizes and allows for the financial flows among major sectors of a regional economy. Institutional issues, such as adherence to DOE policies or feasibility of private participation, should also be addressed. Societal concerns that are not fully addressed in the economics or institutional issues analyses may be studied through sociological and comparative value studies. Focus groups or local leaders can be used to identify issues and assess their significance.

- **Environmental, Safety, and Health Impacts.** The environment, safety, and health performance measures address the operational risk and avoided risk to the local workers, outside public, and the environment as a whole, associated with each alternative. A key element of Life Cycle Assessment is the study not only of the immediate impacts of each alternative, but also the secondary and indirect impacts that may occur upstream or downstream of the decision. For example, disposal alternatives necessitate some production of virgin metal to replace the metal disposed, therefore the releases of hazardous materials, occupational hazards, and resource use during this production of virgin metal are included in the impacts of the disposal alternatives. Care must be taken in this process to avoid double counting.

2.1.3 Identify alternatives

This is the step in the methodology where the specific alternatives to be considered are defined. This step also includes a generic description of the system of activities (the general processes) that are involved in carrying out each alternative as well as identification of the potential impacts of each proposed alternative. For example, in a metal melt option, the key steps of metal extraction, packaging, and shipment to a smelter would be outlined, as well as the key decisions and other issues that might be faced in carrying out that alternative. Selection of alternatives is a crucial step for any decision-aiding approach, because the comparison of alternatives is obviously limited to the alternatives identified.

The process of generating alternatives for evaluation should be done in an iterative manner, in consultation with the stakeholders, and the alternatives should be refined as the understanding of the decision problem deepens. In practice, one must reduce the number of possible alternatives to a manageable group of candidate alternatives, which will then be compared with each other. Based on an initial analysis, new, improved alternatives should be defined and evaluated. This process requires the balancing of the time and effort required to evaluate additional alternatives against the likelihood that a more cursory evaluation will inadvertently eliminate some of the best alternatives.

A large number of potential alternatives currently exist for the disposition of the RSM at the FEMP. These alternatives include, at the extremes, total disposal and total recycle. The optimal alternative may prove to be some partial recycle alternative, in which some metal is recycled and the remaining metal is disposed. There are many different types of metals present at the FEMP, and it may prove desirable to treat the different types of metals in different ways. In

addition to reflecting different metal types, the timing of metal disposition may be an important factor in the development of alternatives. The optimal alternative may well prove to be a phased, hybrid approach, rather than a "total disposal" or "total recycle" option.

2.1.4 Define analytical methods

In this step the analytical models and tools are defined that will be used to evaluate the alternatives on the performance measures. The ultimate objective of this step is to identify the analytical approaches that result in the most defensible analyses, given available data and time and budget allowances. There are a number of specific tools that may be used for the assessments, ranging from sophisticated analytical methods to simple qualitative discussions. While individual tools may be selected for each performance measure, it is important to note that there will be substantial interactions between the models and methods used to evaluate the different performance measures.

In general, the size and level of detail of the analysis should be determined appropriate to the problem, based on the size of the problem, its importance, complexity, imminence, the quality and quantity of available information, the nature of the statutory language, sensitivity of the results to the choice of alternatives, and the likelihood that the analysis may influence the eventual decision. Ultimately, the choice of tools should be made in consultation with the stakeholders and will depend on both the desired size of the overall analysis and judgments about which performance measures should receive the greatest attention.

2.1.5 Assess the impacts of the alternatives

In this step of the Life Cycle Assessment, the analytical tools developed are used to evaluate the impacts of the alternatives on the performance measures. At this stage, the opportunity exists to re-assess the initial assumptions, objectives, and scope that were developed in the Define Decision Parameters stage.

2.1.6 Summarize results

The output of the Life Cycle Assessment phase is a matrix with the alternatives along the top row of the matrix and the performance measures along the side. Within each cell of the matrix will be the value of the performance measure for that particular alternative. This "value" can be a monetized value, such as financial costs and revenues expressed in dollars, a numerical value expressed in some non-dollar metric, such as tons of pollutant or expected number of injuries, or this value can be a qualitative statement, such as the institutional and regulatory issues raised by the alternative. This matrix will provide the essential information needed for negotiations and decision-making. It will help in making the discussions more concrete and allow the key issues to be brought into the open. Discussions can center on the relative importance of one factor versus another, rather than the alternatives as a whole. Oftentimes, based on the results reported in the matrix, one alternative will stand out as the best or some alternatives will be seen to be clearly inferior.

2.2 Decision phase

It can be expected that not all performance measures will favor one alternative. When there is no clearly superior alternative across all performance measures, decisions must be made regarding which performance measures are more important and what is the relative value to assign achievement on different performance measures. Much work has been done to develop structured approaches for analyzing tradeoffs between competing objectives. We provide here a description of some of the methods for measuring and commensurating the values between dissimilar performance measures. These methods can help inform decision-makers on their choices, but they must be recognized solely as tools to assist decision-makers, not replace them.

Given the manner in which an individual's preference information can be elicited and used, as well as the characteristics of the problem, it is not surprising that the number of specific methods that have been developed is large. However, there are a number of fundamental or more prominent methods that are particularly relevant to the asset disposition problem. These methods include multiattribute value theory (MAVT), multiattribute utility theory (MAUT), and the analytical hierarchy process (AHP) [8].

MAVT is the most widely used method for dealing with and solving multiattribute problems. A number of specific techniques have evolved, but they all share the following operational steps:

- Defining alternatives and criteria.
- Evaluating each alternative separately on each criterion.
- Assigning weights to the criteria.
- Aggregating the criterion weights and the single-criterion evaluations of the alternatives to obtain an overall measure of value or worth.
- Conducting sensitivity analyses and making recommendations.

The principle differences among the different methods lie in the choice of procedures used to scale, weight, and aggregate. MAUT is distinguished from MAVT by the incorporation of the individual's risk attitudes in single attribute utility functions. Operationally, MAUT procedures are similar to that of MAVT with scaling, weighting, and aggregating. AHP differs fundamentally from MAVT and MAUT. AHP is built around three general principles: constructing hierarchies (decomposition), establishing priorities (comparative judgments), and ensuring logical consistency (synthesis of priorities). Simplicity, ease of use, ability to handle large number of criteria, and use of a linguistic scale to quantify difficult criteria are some of the features of the

AHP method. However, there are many analysts that have criticized AHP for being fundamentally flawed because it may produce inconsistent results.

3 Discussion and Conclusions

While the decision methodology presented was developed specifically for analysis of RSM disposition at the FEMP, the methodology is general, and can be applied throughout the DOE to evaluate the costs and benefits of recycling and reusing some RSM, rather than disposing of this RSM in an approved burial site. It is recommended that the methodology be applied to the entire DOE complex in order to take advantage of the economies of scale of metals recycle. The methodology is also applicable to other DOE asset management decisions. Indeed, disposition of DOE's assets provides excellent opportunities for testing Life Cycle Assessment concepts and implementation.

An important component of the decision methodology is the proposed Life Cycle Assessment approach. Government decision-makers have an obligation to make decisions based on the best knowledge, data, and evidence available and to explain those decisions to the public. Life Cycle Assessment provides the means for decision-makers to meet that obligation and a framework for holding decision-makers accountable for their decisions.

Life Cycle Assessment is superior to competing methods for several reasons. First, it allows the consideration of numerous factors in environmental decision-making. In addition to threats to human health, other factors that warrant consideration in decision-making include: cultural and social issues; economic impacts, including local and regional economic impacts; short-term and long-term ecological impacts, including damage to natural resources; future land use; schedule impacts such as the ability to complete cleanup projects in a given year; and total cost over the entire life of the project. These and other issues of importance to regulators, public stakeholders, and others can be considered in a Life Cycle Assessment, while they are often ignored in other analyses.

The Life Cycle Assessment approach proposed here has other benefits as well. Life Cycle Assessment allows for the identification of impacts to specific communities and regions, making possible the explicit consideration of environmental justice issues. Life Cycle Assessment provides a framework for searching for efficient solutions to environmental problems. Because there are so many important needs competing for society's scarce resources, it is essential to strive for efficient decisions for protection of health and the environment. Resource limitations are a fact of life; Life Cycle Assessment promotes a substantive public dialogue on how to address these limitations. Contrary to opponents' arguments that this type of analysis promotes governance by elites, Life Cycle Assessment can do just the reverse. By making complex decision-making transparent, understandable and open to scientific and public scrutiny, and by making explicit the complex scientific and value judgments that underlie important decisions, Life Cycle Assessment enables public participation and empowers the public to influence the debate. Unlike informal decision-making methods that obscure the role of assumptions and value judgments in environmental decision-making, Life Cycle Assessment makes them explicit so they can be debated openly.

The proposed Life Cycle Assessment approach differs from traditional life cycle assessments because it considers the environmental, economic and other impacts of concern to stakeholders, and addresses secondary and indirect impacts that may occur upstream or downstream of the decision.

Government decision-makers should not have their decisions dictated by the analysis results because there are many considerations that must be taken into account in any major decision, some of which are not well handled by the Life Cycle Assessment tool. But while acknowledging the limitations of Life Cycle Assessment, we must not allow our search for excellence to stop us from using the best tool available to help us make the hard decisions that need to be made today. Life Cycle Assessment will help decision-makers to reach better decisions and is essential for wise use of society's scarce resources. We can no longer afford the alternative.

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4 References

GRAEDEL, T.E.; ALLENBY, B.R.: Industrial Ecology. Prentice Hall: New York, 1995

HUNSAKER, D.B. Jr; CURLEE, T.R.; ENSMINGER, J.T.; RIVERA, R.G.; YURACKO, K.L.: The Industrial Ecology of Asset Management: A Case Study. Environmentally Conscious Design and Manufacturing, Recent Advances. Volume 4: Proceedings of the Fourth International Congress, Cleveland, Ohio; ECM Press: Albuquerque, NM, 1996

AYRES, R.U., In: The Greening of Industrial Ecosystems. Allenby, B.R.; Richards, D.J. (Eds.) National Academy Press: Washington, D.C., 1994

HILL, L.J.; HUNSAKER, D.B.; CURLEE, T.R.: The Principles of Life-Cycle Analysis. Oak Ridge National Laboratory: Oak Ridge, TN, 1996

YURACKO, K.L.; HADLEY, S.W.; PERLACK, R.D.: Decision Methodology for Fernald Scrap Metal Disposition Alternatives. Oak Ridge National Laboratory: Oak Ridge, TN, 1996

RIVERA, R.G.; YURACKO, K.L.; CURLEE, T.R.; HADLEY, S.W.; CLINARD, J.C.; SNYDER, B.: Asset Management Decisions Using Life Cycle Assessment: A Case Study at the Oak Ridge K-25 Site (Proceedings, Waste Management '96) Tucson, AZ; 1996, In Press

Society of Environmental Toxicology and Chemistry: A Technical Framework for Life-Cycle Assessment. Washington, DC, 1991

PERLACK, R.D.; BEIM, G.K.; BOWMAN, D.C.; HOBBS, B.F.: Multicriteria Decision Frameworks for Technology Ranking Problems. Oak Ridge National Laboratory: Oak Ridge, TN, 1996